PB84-130384

Field Evaluation of Aeration Processes for Organic Contaminant Removal from Groundwater

Nebolsine Kohlmann Ruggiero Engineers, New York

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

1983

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-130384

EPA-600/D-84-016
1983

FIELD EVALUATION OF AERATION PROCESSES FOR ORGANIC CONTAMINANT REMOVAL FROM GROUNDWATER

by

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and
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EPA Cooperative Agreement CR806355

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CINCINNATI, OH 45268

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/D-84-016	2.
3. RECIPIENT'S ACCESSION NO. PB84 130384	
4. TITLE AND SUBTITLE: FIELD EVALUATION OF AERATION PROCESSES FOR ORGANIC CONTAMINANT REMOVAL FROM GROUND WATER	5. REPORT DATE: 1983
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): Dominick D. Ruggiero and Walter A. Feige	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Nebolsine, Kohlmann, Ruggiero Engineers, P.E. New York, NY 10001	10. PROGRAM ELEMENT NO. BNC1A
	11. CONTRACT/GRANT NO. CR806355
12. SPONSORING AGENCY NAME AND ADDRESS: Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED: AWWA Proceedings -Natl Meeting
	14. SPONSORING AGENCY CODE - 1983 EPA/600/14

15. SUPPLEMENTARY NOTES: Project Officer: Walter Feige 513-684-7496

16. ABSTRACT

The results of the pilot plant evaluation of aeration methods for the removal of volatile organic solvents from ground water are presented. The project took place at Glen Cove, Long Island, New York, where the concentration of cis-1,2-dichloroethylene, trichloroethylene, and tetrachloroethylene in that community's well water exceeded State Guidelines. Several aeration approaches were examined, including diffused aeration, packed column diffused aeration, cooling tower aeration, induced air spray aeration (with and without packing), packed column air-stripping, and air-lift pumping. Air discharging from some of the units was sampled for potential air pollution problems. Capital and operating costs were estimated for full-scale installations.

Several of the systems evaluated reduced contaminant levels to meet present New York State guidelines.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT: Release to Public	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 27
	20. SECURITY CLASS (This page): Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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FIELD EVALUATION OF AERATION PROCESSES FOR ORGANIC CONTAMINANT REMOVAL FROM GROUNDWATER

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and
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INTRODUCTION

The discovery of contaminated groundwater in the United States and throughout the world is constantly increasing and becoming a major concern to public health officials. This is especially true for areas depending on groundwater as the source of their drinking water supply. One such area encompasses the City of Glen Cove, N.Y., where in 1977 a portion of the wells supplying water to the City was restricted from use because of the presence of volatile organics in excess of the New York State guidelines. Faced with the problem of a reduced water supply, the City of Glen Cove began evaluating methods to augment their available supply. The City retained the consulting engineering firm of Nebolsine Kohlmann Ruggiero Engineers, P.C. (NKRE) to determine the most feasible and economical treatment system. Based on discussions with the U.S. EPA's Municipal Environmental Research Laboratory Drinking Water Research Division (MERL-DWRD) in Cincinnati, Ohio, it was determined that no treatment system existed at that time that was capable of treating large volumes of water containing the organic contaminants present in the Glen Cove groundwater. After preliminary testing, funded by the City of Glen Cove, discussions and negotiations between the City of Glen Cove, the U.S. EPA and NKRE resulted in a research grant (later changed to a Cooperative Agreement) funded by the U.S. EPA to test several possible treatment methods at the Glen Cove site. The research program was operated in three phases, beginning in the latter part of 1978 and was completed in the first quarter of 1983. While the actual testing involved several possible treatment methods, such as adsorption, this paper will present the results of the testing of aeration methods.

Aeration - General

The use of aeration for the effective removal of volatile organics was questionable at the beginning of this research project. Very little was known at that time about the ability of aeration procedures to remove volatile organic contaminants from groundwater. It was only after preliminary testing at Glen Cove using aeration (1) and after testing by the U.S. EPA in their Cincinnati, Ohio, laboratory on water spiked with organic contaminants (2) that it was concluded that aeration should be included as a part of the research project. Aeration technology has developed substantially during the period of this project. It has advanced from a questionable approach to one of the best and most economical methods of removing volatile organic contamination from a groundwater supply.

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The testing at the Glen Cove site has also proven that the use of aeration has little or no impact on the ambient environment since, unlike other treatment technologies, such as adsorption, aeration does not require recovery, regeneration or chemical use and does not produce a waste product for disposal. The amounts of contaminants stripped from the water also have insignificant impact on the ambient air. During the research project several aeration approaches were tested. These included: diffused aeration, packed column diffused aeration, cooling tower aeration, induced air spray aeration (with and without packing), packed column air-stripping and air-lift pumping.

Aeration Testing Pilot Plant Facilities

Following the approval of the initial request and each phase extension, the plans were reviewed with U.S. EPA (MERL-DWRD). After approval by DWRD the necessary equipment was purchased and installed or the required modifications were made to the existing testing equipment.

The testing in all three phases was located at the Carney Street well site in Glen Cove, N.Y., where the highest concentrations of contaminants were found. Well No. 22, which draws water from an aquifer about 160 feet (49 m) below ground level and has a pumping capacity of about 2 mgd (7570 m3/day), was utilized as the main water supply to the test units in all three phases.

The required analysis for all phases was performed on analytical instrumentation purchased in Phase I. The analytical instrumentation shown on Figure 1 included a Tracor* gas chromatograph equipped with a halogen-specific electrical conductivity detector and a Tekmar purge-and-trap concentrator. The gas chromatograph was also equipped with an automatic integrator which determined the area of the peaks and printed out the results.

The aeration method tested during Phase I, diffused aeration, was the only method tested during all three pilot plant phases. The water to be treated by diffused aeration flowed first through an impact flow meter and a flow totalizer before entering an acrylic aeration column, shown on Figure 1. The influent water entered at the top of the column and discharged through a pipe attached about 2 feet (0.61 m) above the base of the column. Air for the unit was supplied by a blower (shown on Figure 1) and the air flow was measured by a manometer. Air was diffused at the bottom of the column by five cylindrical porous stone diffusers. This arrangement resulted in the air flowing countercurrently to the water.

Phase II aeration testing included use of the diffused aeration column previously described and the addition of a packed column diffused aeration unit and a small cooling tower (Manufacturer's demonstration unit). These units are shown on Figure 2. The packed column diffused aeration unit consisted of an acrylic column identical to that used for the initial diffused aeration testing. Six feet of packing material, purchased from Munters Corporation, was placed in the column. Air was supplied to this column below the packing by the blower used in Phase I and was distributed either by cylindrical porous stone diffusers or a hole in an air pipe at the center of the packing. The cooling tower unit installed was a small demonstration model of an induced draft cooling tower provided by Baltimore Air Coil

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(shown on Figure 2). This model is based on a self-sustaining aeration system requiring no outside source of energy other than the water pressure itself.

Utilizing the results of Phases I and II and after consultation with the U.S. EPA, major additions and modifications to the pilot plant equipment were made for the Phase III testing. The modifications included modifying an aeration column so it could be used to evaluate air spray aeration, utilizing induced air, the installation of an air-lift pump in a well, and the addition of a second blower.

To evaluate induced draft air spray aeration one of the columns used in Phase II was modified by installing a spool placed between the base and the first section to allow ambient air to enter. A fan was installed on the top of the column to draw the air up through the column. The water was supplied to the column through a distribution header, the configuration of which was varied during the test period. The column was initially operated empty but the Munters packing, purchased in Phase I, was added during the test period.

During the Phase III test period U.S. EPA personnel delivered, installed and operated a mobile packed column air-stripping unit at the Glen Cove site (3). This unit contained about 18 feet (5.51 m) of 1-inch (2.5 cm) plastic saddle packing purchased from Glitsch Company. The water entered the top of the column and ambient air was induced at the base of the packing.

Well No. 20 at the Carney Street site was converted to an air lift pump operation so that this approach to air-stripping could be evaluated. This was accomplished by pulling the existing pump in Well No. 20 and replacing it with a fabricated air lift pump. This pump utilized the air from one of the blowers of the diffused aeration system as its air supply. The units for Phase III are shown on Figure 3.

Aeration Testing Program and Operations

The main objective of the aeration portion of this research program was the evaluation of the basic effect of aeration methods for the removal of trichloroethylene, tetrachloroethylene, cis-1,2-dichloroethylene and 1,1,1-trichloroethane from groundwater sources used as drinking water supplies. The pilot plant program evaluated the aeration methods at various air to water ratios, various distribution configurations and water application rates.

The diffused aeration and packed diffused aeration columns had a constant water flow of 28 gal/min (6.4 m3/hr) which corresponded to a residence time of about 10 minutes. The air to water ratio was varied by changing the air flow. Air to water ratios for the three phases varied from 5:1 to 30:1. Since the packed column diffused aeration system had two methods of introducing air (spargers and a hole in the air pipe) both were tested.

The small demonstration cooling tower unit generated its own air draft requiring the air to water ratio to be determined by field measurements. The air to water ratio was related to the incoming water pressure.

The air to water ratio for the induced air spray aeration column was varied by changing the water flow to the column because the fan installed at the top of the column had a constant speed producing 2500 cfm

of air. The distribution system at the top of the column was altered several times and the final arrangement included five nozzles manufactured by Spraying Systems Co. The column was initially operated empty with packing added in the later part of the program.

The packed column air-stripping unit is a portable test unit which was tested at the Glen Cove site twice by U.S. EPA personnel during the third phase of this research program. The column contains approximately 18 feet (5.49 m) of plastic saddle packing and is 24 inches (0.61 m) in diameter. The column was tested at air to water ratios ranging from 5:1 to 85:1. The ratios were changed by varying both the speed of the blower inducing the ambient air and the water flow.

Samples of the appropriate influent from Well No. 22 and the effluent from each test unit were sampled for analysis on the scheduled sampling days. Units which did not run continuously were operated for at least one hour before sampling occurred.

The only system which did not have Well No. 22 as the source of the water being tested was the air-lift pump which was installed in Well No. 20. The air to water ratio was varied by increasing or decreasing the submergence of the air pipe in the well and varying the air applied to the well. Flow from the pump was computed using the measured flow over a 90 degree V-Notch weir. The influent sample was taken from the same well using a pipe installed outside the eductor pipe of the air-lift pump. Prior to sampling the effluent the pump was allowed to operate for one hour to insure stability.

Since aeration processes transfer contaminants from the water to the ambient air it was necessary to determine the impact on the ambient air. To accomplish this air samples of the air discharging the various units were taken and analyzed for the contaminants under study.

RESULTS

Diffused Aeration Studies

The only aeration method which was tested in all three phases was the diffused aeration method. This approach was operated at air to water ratios of 30:1, 20:1, 15:1 and 5:1. The results of the Phase I operation, which are summarized on Figure 4, indicate that diffused aeration can meet the present New York State guidelines for the contaminants tested which was also confirmed in Phases II and III. These guidelines are 50 ug/l per contaminant and a total of 100 ug/l for all organic contaminants.

Testing in Phase II, which involved the evaluation of packed column diffused aeration and two-stage diffused aeration, indicated an improvement in removal efficiency using two stages or packing. The packed column diffused aeration system, which operated with the packing flooded and unflooded and used two methods of air distribution, showed removals similar to those achieved by plain diffused aeration but at lower air to water ratios. This was achieved using the unflooded conditions with air distribution utilizing porous sparger stones. A summary of the data is presented on Tables 1 and 2 and summarized graphically on Figure 5. The two-stage diffusion aeration results, which are summarized on Table 3, indicate that for a given air to water ratio, two-stage operation resulted in substantially greater removals than single-stage operations.

Induced Air Spray Aeration Studies

The original reason for testing this approach was to determine the effect of spray aeration as a method of removing volatile organics from a water supply. The initial approach was the use of several nozzle arrangements to distribute the water across the column. It was determined after initial testing that the contact time between the water and air in the column was insufficient to achieve desired removal efficiencies. Since it was not possible to increase the height of the column, packing was added in stages and the induced air packed column spray aeration approach was evaluated. Packing manufactured by Munters Co. was installed in the column. The first evaluation utilized two feet of the packing which was increased to four feet. With four feet of the packing it was possible to remove more than 90% of the organics present and produce water of a quality which should be acceptable under most conditons. Typical results are shown on Figure 6. Due to project time constraints it was not possible to further increase the depth of packing.

Packed Column Air Stripper Studies

Twice during the Phase III operation U.S. EPA personnel installed and operated their own packed column air stripper at the Glen Cove, N.Y., site. The unit operated with approximately 18 feet of plastic saddles, manufactured by Glitch, Inc., and was operated at air to water ratios ranging from 5:1 to 85:1. The removal efficiency ranged from 60 to greater than 95 percent depending on the air to water ratio used. This approach produced a water quality meeting present New York State guidelines and most other areas at air to water ratios of 15:1 or greater. Typical results of the testing at the Glen Cove site is shown graphically on Figure 7.

Air-Lift Pumping Studies

Since there was no commercially available air-lift pump to suit the desired operating conditions the pump utilized for this study was fabricated on site. Since the only data available on air-lift pumping as an air-stripper indicated that a minimum 10:1 air to water ratio was required, all testing was performed at ratios of that level or higher. The testing results indicated that the removal efficiency of this method of air stripping was low, with only about a 50% reduction in the overall average organic removal. A summary of the results is presented on Table 4. It should be noted that many problems in operations were encountered and considering the relatively poor results, it was evident that the air-lift pumping system did not appear suitable as a practical method for efficient removal of organic contaminants from water.

Cooling Tower Studies

A small demonstration model of an induced draft cooling tower was evaluated during Phase II. Utilizing an air flow meter it was determined that this unit was capable of producing air to water ratios ranging from 200:1 to 700:1 at flow application rates of 2 gpm to 4 gpm respectively. Based on testing in this range, the removal efficiency was rather low, between 48 and 61 percent average for the contaminants present. However, it should be emphasized that the unit used was a demonstration unit for sales purposes and a unit designed for a specific purpose, or another type of cooling tower unit, could possibly be suitable for the treatment of contaminated groundwater.

Air Sampling

There has been concern about the transfer of contaminants from the water to the ambient air, thereby causing an air pollution problem. To study this problem, air sampling and analysis were conducted on the air discharging from several of the systems evaluated in addition to the ambient air in the area. The major portion of this sampling was performed during Phase III. These data, along with the computed theoretical values, are presented on Table 5. Also included in Table 5 are OSHA 8-hr workroom standards (4), the only air quality standards known to exist for these contaminants. In many instances, the levels found were higher than the computed theoretical value. This discrepancy was believed to have been caused by the pickup of moisture in the air sample which would not have been a factor if a mist eliminator were used. When comparing the actual analytical results, the computed theoretical values for the discharged air and the OSHA workroom standards, it is apparent that none of the aeration systems had any appreciable impact on the air in the vicinity of the treatment units and after dilution with the contaminant-free ambient air, the contaminants would be at levels below the detection limits.

Ambient Air Effect on Water Quality

The ambient air used in the induced aeration system may have an effect on the quality of the treated water and to evaluate one aspect of this possible effect, suspended solids and particulate analyses were performed on the influent and effluent to each aeration method tested in Phase III. The results of this testing indicates little to no effect on the treated water quality. It should be noted that the ambient air in the Glen Cove area is relatively clean and the effect must be evaluated in an area where air pollution is present. If high dust loads are present in the ambient air, a significant solids load could be imparted to the treated water.

Aeration Studies Summary

The data developed during the research project for all six aeration methods tested are compared and summarized on Table 6. This summary indicates that the best removals were achieved by the packed column air stripper closely followed by the induced air packed column spray aeration system. The lowest overall removal was achieved by the air-lift pumping system.

Estimated Costs for Full-Scale Installations

The diffused aeration system, packed column diffused aeration system, induced air packed spray aeration system, and packed column air stripper can be designed and installed for a full-scale operation. The units will be capable of meeting the present New York State guidelines and produce a quality of water which should be acceptable in most other areas. Further evaluation of the air-lift pump system must be made before a decision as to the adaptability of these systems can be made.

Flows of 1, 2 and 5 mgd (3,785, 7,575 and 18,925 m3/day) were utilized to obtain a range of costs for a full-scale installation. The cost estimates are based on costing information available in February 1983. All estimated capital costs include required buildings for mechanical and electrical equipment but not laboratory, offices or facilities for

workmen. The estimated capital cost for five of the aeration systems tested during this research project are compared on Figure 8. These estimated capital costs indicate that the packed column air-stripper system has the lowest capital cost, and the packed column diffused aeration system has the highest estimated capital cost. A comparison of the estimated annual operating cost per 1000 gallons (3,785 liters) of treated water considering an electrical cost of $0.09/kWh for all systems tested is presented on Figure 9. These estimated annual operating costs for the systems show that the packed column air-stripping system has the lowest operating cost while the air-lift pumping system has the highest operating costs.

CONCLUSIONS

General

The following conclusions are applicable to all aeration methods tested during the three phases except as noted under the particular process unit.

1. Aeration as a technique for the treatment of volatile organics present in groundwater will reduce cis-1,2-dichloroethylene, trichloroethylene, tetrachloroethylene and 1,1,1-trichloroethane, to levels which will meet present New York State guidelines and to levels that may be universally acceptable.

2. Most of the systems evaluated can be detailed designed and a full-scale plant installed. Some of the systems will require additional testing to determine the most economical design parameters.

3. There is no apparent effect on the ambient environment. Air discharging from the units contains levels of contaminants below any existing air standards and the concentrations may not be measurable after mixing with the ambient air. The aeration units do not produce any liquid or solid wastes which must be disposed and, therefore, will have no impact in that respect.

4. There is no apparent effect on the final water quality particular levels contributed by ambient air quality for systems using induced ambient air. This is based on the ambient air conditions at the Glen Cove, N.Y., site and should be confirmed at other sites, especially in areas where air pollution is prevalent.

Diffused Aeration Studies

1. To achieve desirable water quality the diffused aeration system must operate at an air to water ratio of 15:1 or higher. Using this air to water ratio the system will remove between 60-95 percent of all compounds tested with an average overall removal of approximately 84 percent.

2. The removal efficiency can be increased by adding a second stage diffused aeration unit or possibly by increasing the height of the diffused aeration unit.

Packed Column Diffused Aeration Studies

The use of packing material produced a slight improvement over that of diffused aeration, achieving an overall removal of contaminants at about 83 percent using air to water ratios of 10:1. The system must be operated with the packing above the operating water level to achieve these results.

Induced Air Spray Aeration Studies

The testing in Phase III concluded that this approach required packing in the unit to provide enough air to water contact time to achieve acceptable levels. Using at least 4 feet (0.12 m) of Munters Corporation packing the overall reduction of organic contamination was better than 90 percent.

Packed Column Air-Stripping

The test column used for this evaluation was designed and delivered to the site by U.S. EPA personnel who installed it and operated it during the two test periods. This unit used plastic saddles, purchased from Glitsch, Inc., and had the highest overall removal efficiency, exceeding 95 percent, of all aeration methods evaluated.

Air-lift Pumping Studies

The system exhibited very poor efficiency, about 50 percent, in removing the volatile organics. This approach requires additional evaluation before it can be considered for full-scale operation.

Induced Draft Cooling Tower Studies

The unit used to evaluate this method was a small demonstration model supplied by Baltimore Air Coil. It was difficult to control the air to water ratio and the unit had a rather low removal efficiency between 48 and 61 percent. The water quality produced did not meet present New York State guidelines and the unit is not considered ready for full-size scale-up. Additional testing is required before this type of unit could be recommended for a full-sized installation.

RECOMMENDATIONS

Reviewing the data developed during this entire research project, it is apparent that information is dependable for some systems to allow for the design and installation of full-scale units while others require additional testing to determine the optimum and most economical design parameters. Some of the units evaluated do not appear to be feasible and additional testing is not warranted. The following are recommendations to further develop the treatment system to remove organic contamination from a groundwater supply which should be considered for other research projects:

1. A full-scale demonstration plant should be installed to evaluate air-stripping of contaminants on a continuous basis.

2. Additional testing should be performed to evaluate the economics and optimum conditions for several types of packing material, including the proper hydraulic loading and air to water ratio for each type of packing.

3. The effect of ambient air conditions on systems utilizing induced ambient air should be further evaluated and expanded to include potential contaminants other than suspended matter, e.g., bacteria and viruses. The testing should be conducted in a potentially high air pollution area.

REFERENCES

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(2) Private Communications with Dr. O.T. Love, U.S. EPA, Cincinnati, Ohio, November 1977.

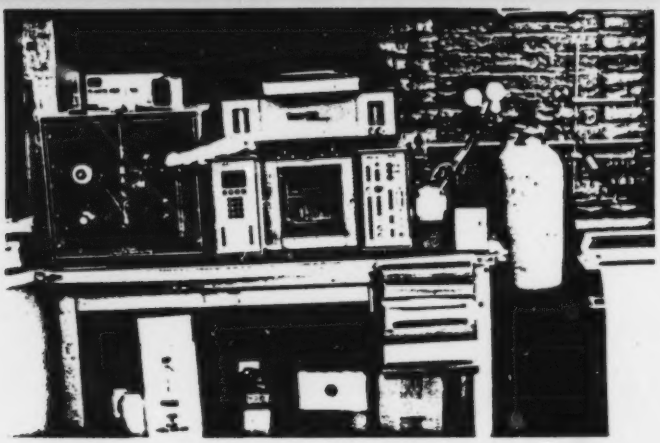
(3) Michael D. Cummins and James J. Westrick, "Packed Column Air Stripping for Removal of Volatile Compounds," 1982 Conference of Environmental Engineers, American Society of Civil Engineers.

(4) General Industry Standards OSHA Safety and Health Standards (29 CFR 1910) U.S. Department of Labor, Occupational Safety and Health Administration, OSHA 2206, Revised November 7, 1978.

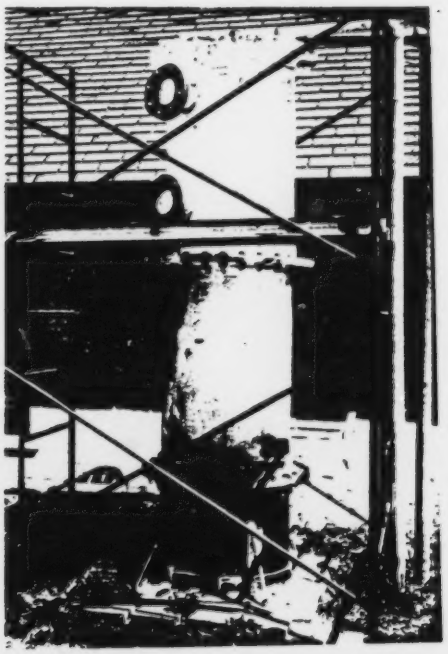
(5) "Removal of Organic Contaminants from Drinking Water Supply at Glen Cove, N.Y.: Phase I," U.S. EPA - 600/2-80-198 (1980).

(6) "Removal of Organic Contaminants from Drinking Water Supply at Glen Cove, N.Y.,: Phase II," U.S. EPA - 600/2-82-027 (1981).

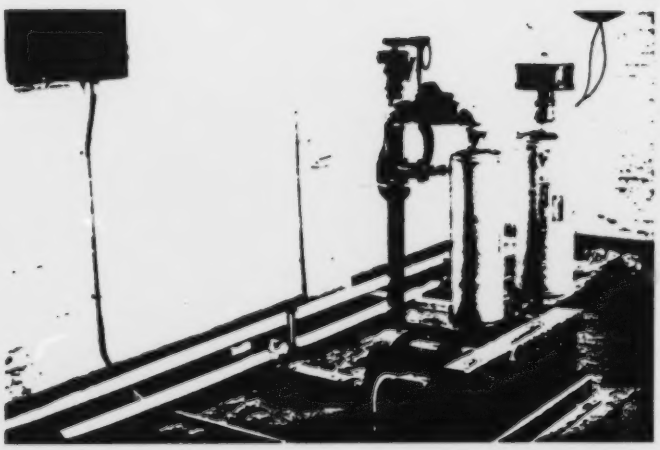
(7) "Removal of Organic Contaminants from Drinking Water Supply at Glen Cove, N.Y.: Final Report," Final Draft.



(a) Phase I - Analytical Instrumentation

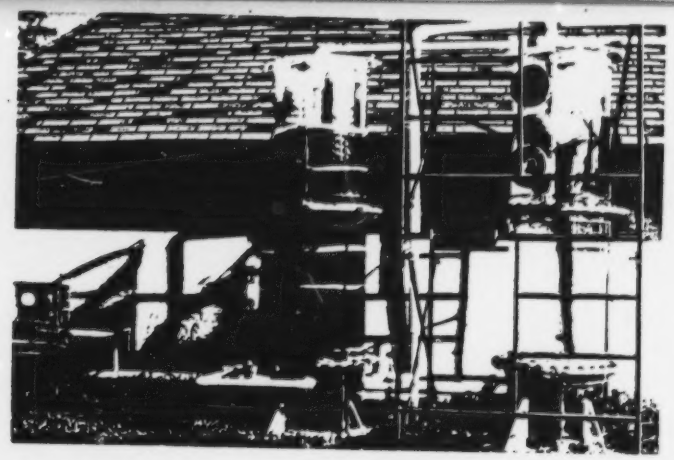


(b) Phase I - Diffused Aeration Column



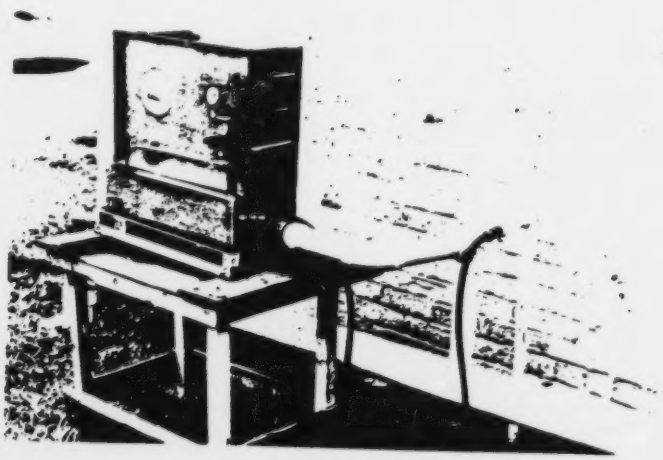
(c) Phase I - Blower for Diffused Aeration Column. On the wall is the manometer which measures the air flow.

FIGURE 1



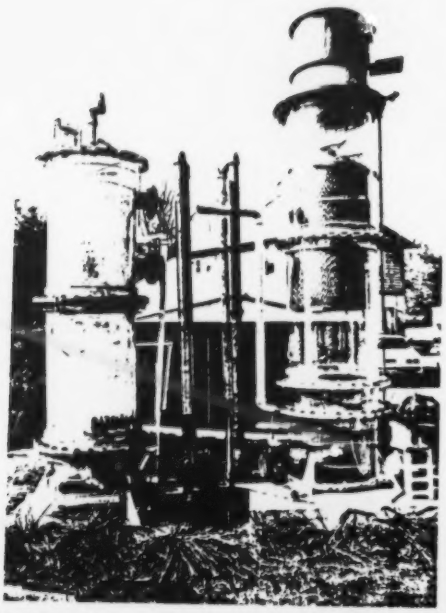
Phase II - Aeration Testing (Induced Draft Cooling Tower, Packed Aeration Column and Diffused Aeration Column from Phase I)

Phase II - Packed Aeration Column

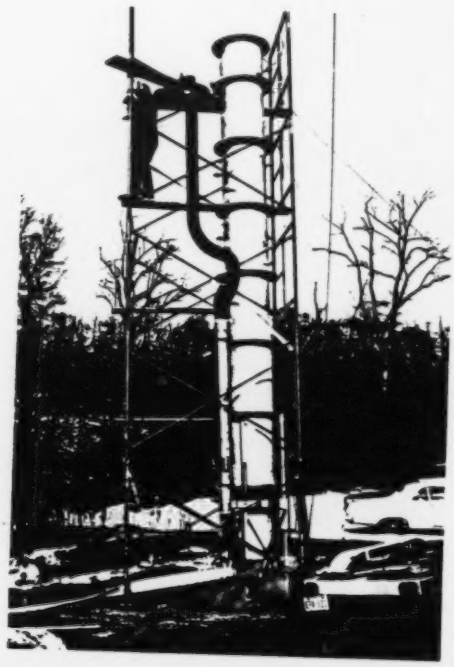


Phase II - Induced Draft Cooling Tower

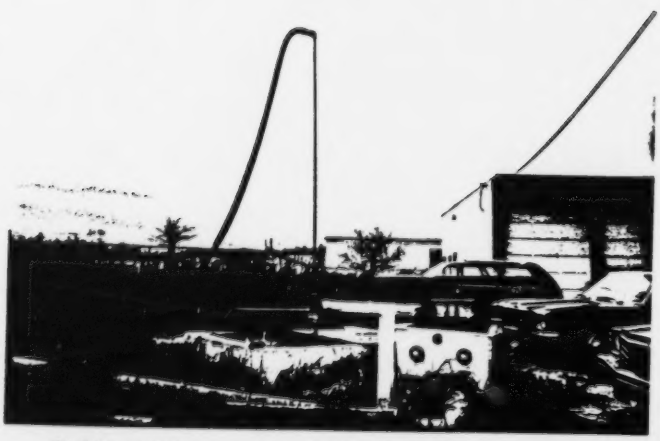
FIGURE 2



PHASE III - Diffused Aeration Column and Spray Aeration Column with Packing.

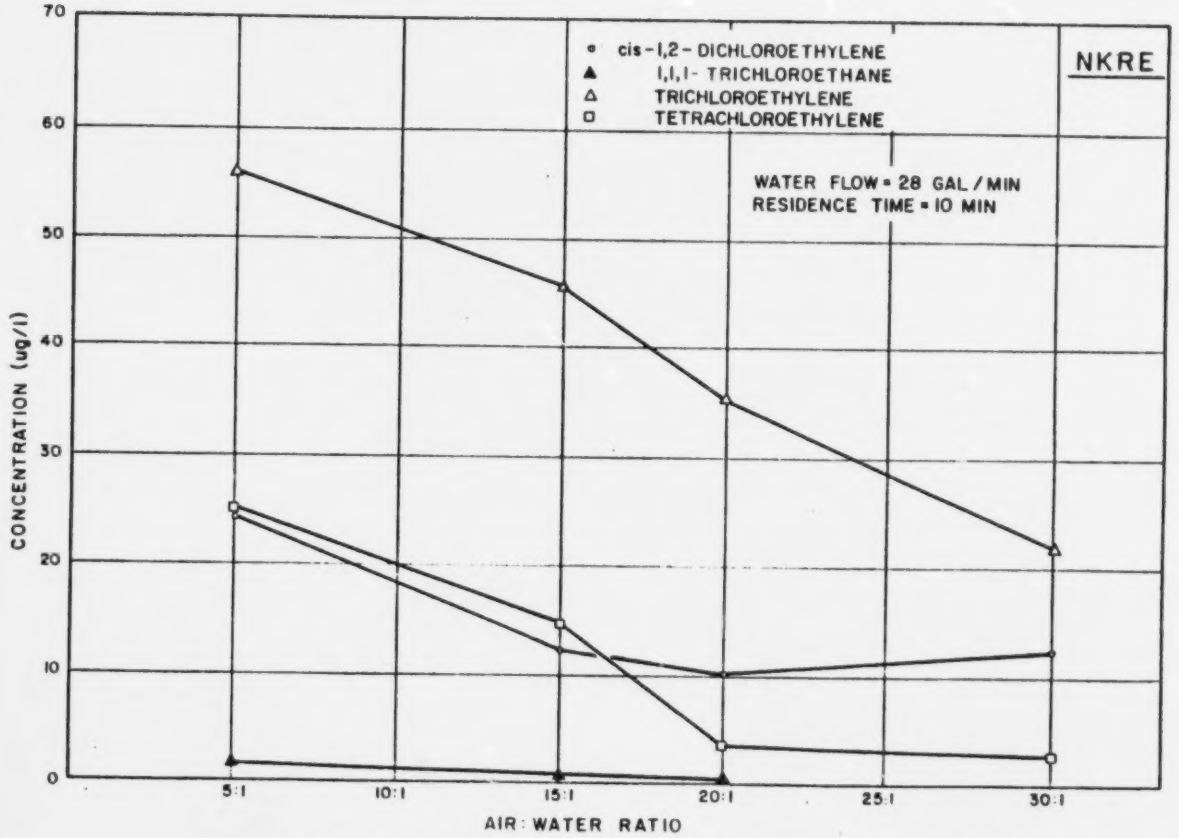


Phase III - U.S. EPA's Packed Air Stripping Column



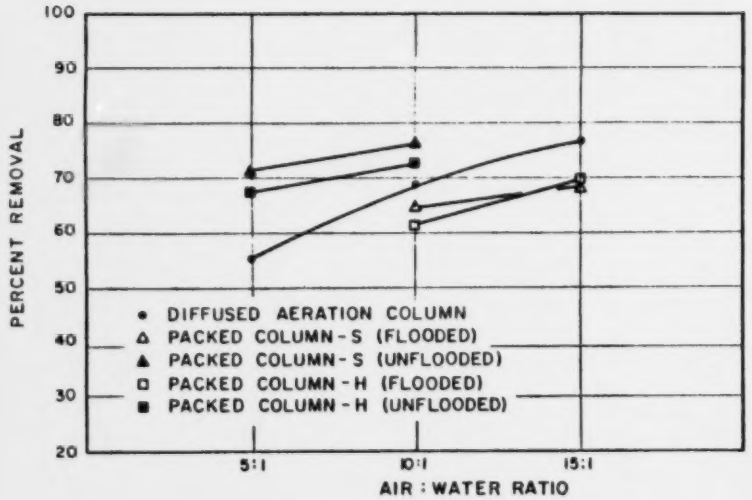
PHASE III - Air-lift Pumping System

FIGURE 3



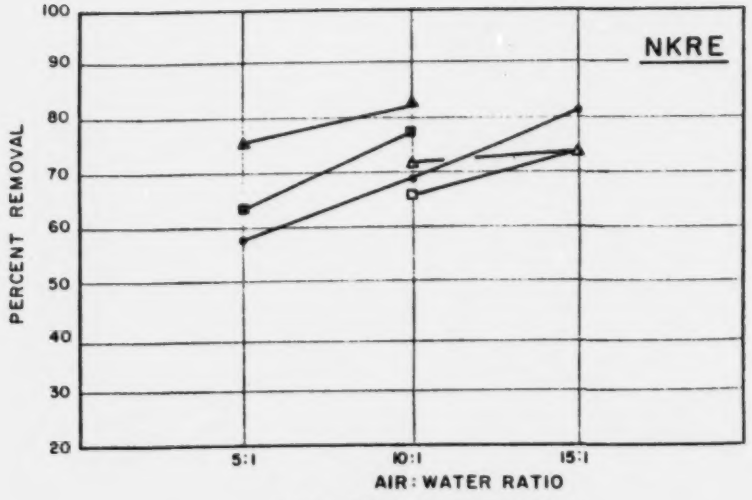
AVERAGE AERATION EFFLUENT LEVELS AT SELECTED AIR:WATER RATIOS

FIGURE 4



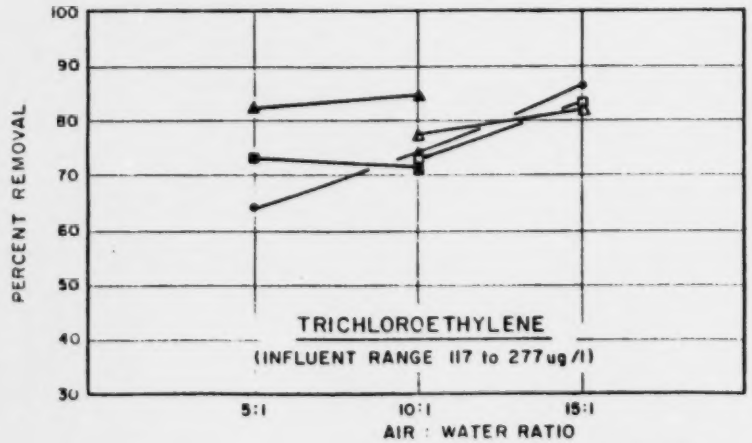
CIS - 1,2 - DICHLOROETHYLENE

(INFLUENT RANGE 28 to 79 ug/l)



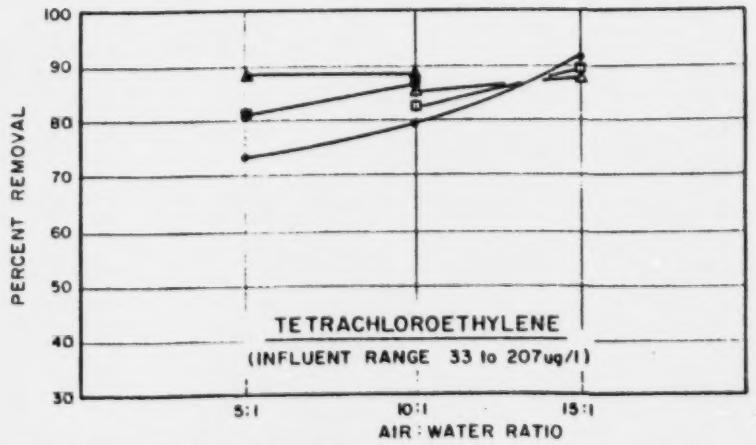
1,1,1 - TRICHLOROETHANE

(INFLUENT RANGE 3 to 7 ug/l)



TRICHLOROETHYLENE

(INFLUENT RANGE 117 to 277 ug/l)



TETRACHLOROETHYLENE

(INFLUENT RANGE 33 to 207 ug/l)

AVERAGE PERCENT REMOVALS AT SELECTED AIR : WATER RATIOS

FIGURE 5

TABLE 1. AERATION COLUMNS PERFORMANCE (Average values in ug/l)

Air: Water Ratio	Contaminant	Aeration Column			Packed Column-S* (Flooded)			Packed Column-S* (Not Flooded)			Packed Column-H* (Flooded)			Packed Column-H* (Not Flooded)		
		Ave. Infl.	Ave. Effl.	Ave. Remov.	Ave. Infl.	Ave. Effl.	Ave. Remov.	Ave. Infl.	Ave. Effl.	Ave. Remov.	Ave. Infl.	Ave. Effl.	Ave. Remov.	Ave. Infl.	Ave. Effl.	Ave. Remov.
5:1	cis-1,2-dichloro-ethylene	62.3	27.8	55				62.3	17.8	71				62.3	20.8	67
	Trichloro-ethylene	131.1	47.4	64				131.1	23.0	82				131.1	35.3	73
	Tetrachloro-ethylene	155.7	41.7	73				155.7	18.8	88				155.7	29.8	81
	1,1,1-trichloro-ethane	4.0	1.73	57				4.0	1.0	75				4.0	1.5	63
10:1	cis-1,2-dichloro-ethylene	43.2	13.8	68	41.1	14.6	64	54.7	13.0	76	40.7	16.0	61	54.7	15.1	72
	Trichloro-ethylene	150.2	38.8	74	152.9	35.6	77	149.0	23.4	84	152.9	41.6	73	149.0	28.6	81
	Tetrachloro-ethylene	85.0	17.8	79	75.0	10.9	85	122.0	12.8	88	74.4	13.6	82	122.0	16.7	86
	1,1,1-trichloro-ethane	3.8	1.2	68	3.8	1.1	71	4.0	0.7	82	3.7	1.3	65	4.0	0.9	77
15:1	cis-1,2-dichloro-ethylene	36.5	8.6	76	36.5	11.6	68				36.5	11.2	69			
	Trichloro-ethylene	170.8	23.3	86	170.8	31.0	82				170.8	28.9	83			
	Tetrachloro-ethylene	49.0	4.4	91	49.0	5.9	88				49.0	5.5	89			
	1,1,1-trichloro-ethane	3.7	0.7	81	3.7	1.0	73				3.7	1.0	73			

* Packed Column-S = Column packed using diffuser stones.

Packed Column-H = Column packed with air passing through a hole.

TABLE 2

AERATION COLUMNS REMOVAL EFFICIENCY
(Average Overall Percentage)

Column Type	5:1	10:1	15:1
Diffused Aeration	62	72	84
Packed-S-Flooded	-	74	78
Packed-S-Unflooded	79	83	-
Packed-H-Flooded	-	70	80
Packed-H-Unflooded	71	79	-

Packed Column-S = Column packed using diffuser stones.

Packed Column-H = Column packed with air passing through a hole.

TABLE 3

ORGANIC CONTAMINANT PERCENT REMOVAL
Diffused Aeration Column

Column	Air to Water Ratio	Total Organic Contaminant Percent Removal
1	5:1	76.0
	10:1	73.6
	15:1	82.1
	17:1	76.2
2	5:1	43.1
	10:1	72.1
	15:1	43.9
	17:1	82.5
Combined	5:1	86.5
	10:1	93.3
	15:1	89.9
	17:1	95.5

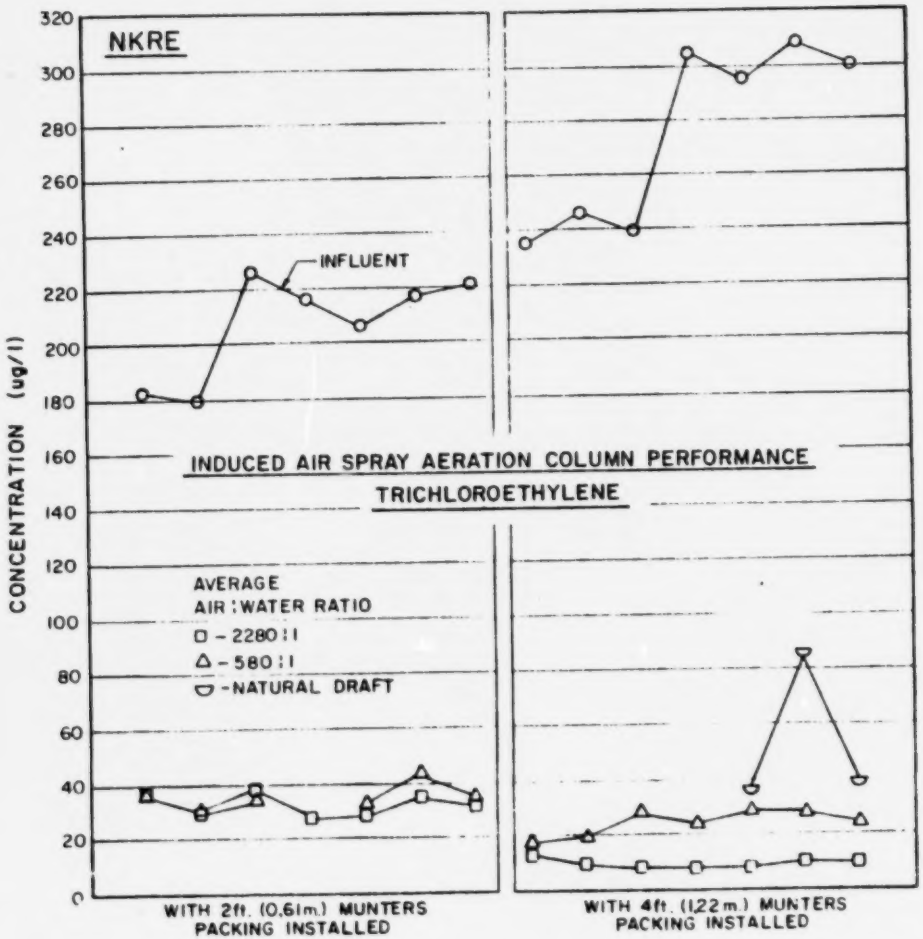

NKRE
INFLUENT
INDUCED AIR SPRAY AERATION COLUMN PERFORMANCE
TRICHLOROETHYLENE
AVERAGE
AIR : WATER RATIO
□ - 2280 : 1
△ - 580 : 1
○ - NATURAL DRAFT
CONCENTRATION (ug/l)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
WITH 2ft. (0.61m.) MUNTERS PACKING INSTALLED
WITH 4ft. (1.22m.) MUNTERS PACKING INSTALLED

FIGURE 6

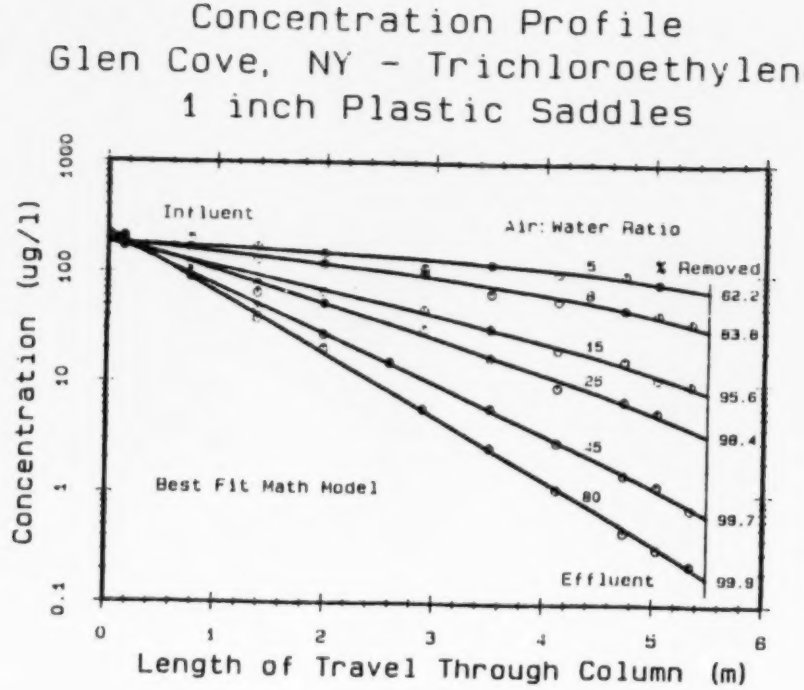

Concentration Profile
Glen Cove, NY - Trichloroethylene
1 inch Plastic Saddles
Concentration (ug/l)
1000
100
10
1
0.1
Influent
Air:Water Ratio
% Removed
5
62.2
8
83.8
15
95.6
25
98.4
45
99.7
80
99.9
Best Fit Math Model
Effluent
0
1
2
3
4
5
6
Length of Travel Through Column (m)

FIGURE 7

TABLE 4

GLEN COVE, N.Y. - PILOT PLANT - PHASE III - AIR-LIFT PUMP SYSTEM
SUMMARY OF RESULTS (All values in ug/l)

Air to Water Ratio	Contaminant	Average Influent (Influent Range)	Average Effluent (Effluent Range)	Average Percent Removal
15:1 to 27:1	cis-1,2-dichloroethylene	67.1 (28 - 129)	41. (18 - 79)	37.8
	trichloroethylene	132.2 (80 - 163)	52.8 (31 - 74)	60.1
	Tetrachloroethylene	8.9 (5.8 - 18)	2.9 (1.1 - 6.3)	67.4
	1,1,1-trichloroethane	1.9 (0.9 - 2.9)	0.8 (NM - 1.6)	57.9
30:1 to 83:1	cis-1,2-dichloroethylene	70.9 (57 - 137)	52.1 (37 - 76)	26.5
	trichloroethylene	133.5 (99 - 148)	62.6 (45 - 73)	53.1
	tetrachloroethylene	7.6 (6.7 - 9.9)	3.3 (2.5 - 6.2)	56.6
	1,1,1-trichloroethane	1.6 (1.2 - 1.9)	0.8 (0.5 - 1.7)	50.0

TABLE 5

GLEN COVE, N.Y. - PILOT PLANT - PHASE III - AIR SAMPLING AND ANALYSIS
SUMMARY OF RESULTS (All values in ppm - volume to volume)

A. Analyses at Glen Cove Site

Testing	Contaminant	Average Values Found	Average Computed Theoretical Values
1. U.S. EPA Packed Column Air Stripper*	cis-1,2-dichloroethylene	11.608	1.99
	trichloroethylene	7.354	2.53
	tetrachloroethylene	0.700	0.29
	1,1,1-trichloroethane	N.D.	0.02
2. Diffused Aeration Column	cis-1,2-dichloroethylene	3.868	1.84
	trichloroethylene	6.163	2.74
	tetrachloroethylene	0.250	0.39
	1,1,1-trichloroethane	1.225	0.04
3. Spray Aeration Column	cis-1,2-dichloroethylene	N.D.	0.02
	trichloroethylene	N.D.	0.02
	tetrachloroethylene	N.D.	0.01
	1,1,1-trichloroethane	N.D.	0.01
4. Air-lift Pump*	cis-1,2-dichloroethylene	N.D.	Not possible to calculate
	trichloroethylene	N.D.	
	tetrachloroethylene	N.D.	
	1,1,1-trichloroethane	N.D.	
5. Ambient Air	cis-1,2-dichloroethylene	N.D.	Not applicable
	trichloroethylene	N.D.	
	tetrachloroethylene	N.D.	
	1,1,1-trichloroethane	N.D.	

B. OSHA Standards (Time Weighted Average - 8-hr period)

Contaminant	Standard
cis-1,2-dichloroethylene	50
trichloroethylene	100
tetrachloroethylene	100
1,1,1-trichloroethane	350

NOTE: Analytical detectable limits: 0.5 ppm
N.D. - Not Detectable (0.5 ppm)

* Based on two sampling occurrences. All others based on four occurrences.

TABLE 6

SUMMARY OF AVERAGE OVERALL PERCENTAGE REMOVAL
FOR AERATION METHODS TESTED AT GLEN COVE, N.Y.

System	Range of Overall Percentage Removal**
1. Diffused Aeration	
A. Single Stage	59-84
B. Two Stages	86-96
2. Packed Column Diffused Aeration	70-83
3. Induced Draft Cooling Tower	53-61
4. Induced Air Spray Aeration	
A. Without Packing - Induced Air	52-77
- Natural Draft	43-63
B. With 2 ft (0.61 m) Packing	80-82
C. With 4 ft (1.22 m) Packing - Induced Air	91-93
- Natural Draft	81*
5. Packed Column Air Stripper	
A. With 1-inch (2.5 cm) Saddles	
- Induced Air	69-97
- Natural Draft	38*
B. With 2-inch (2.5 cm) Saddles	
- Induced Air	63-95
- Natural Draft	72*
6. Air-lift Pumping	46-56

* Results Based on one day of Testing.

** Function of Air to Water Ratio.

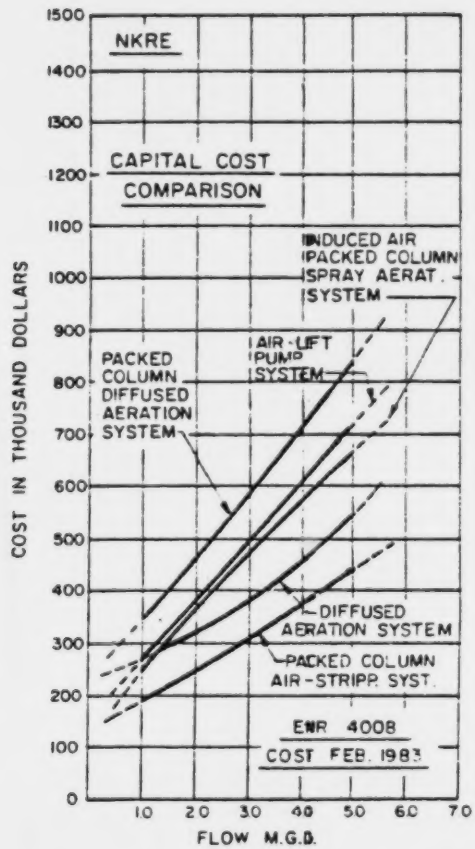

NKRE
CAPITAL COST
COMPARISON
INDUCED AIR
PACKED COLUMN
SPRAY AERAT.
SYSTEM
AIR-LIFT
PUMP
SYSTEM
PACKED
COLUMN
DIFFUSED
AERATION
SYSTEM
DIFFUSED
AERATION SYSTEM
PACKED COLUMN
AIR-STRIPP. SYST.
ENR 4008
COST FEB. 1983
COST IN THOUSAND DOLLARS
FLOW M.G.D.
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
10
20
30
40
50
60
70

FIGURE 8

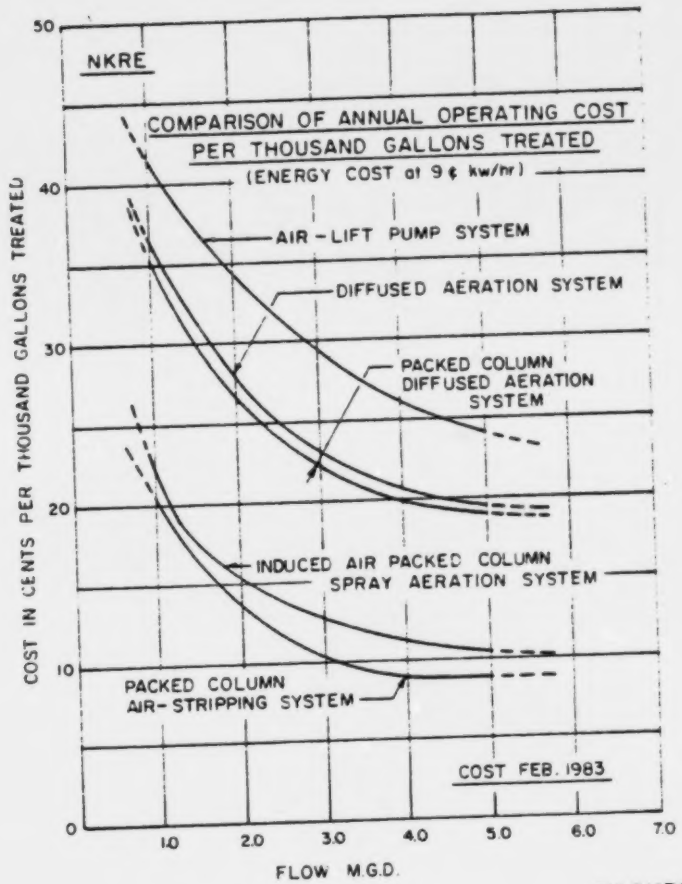

NKRE
COMPARISON OF ANNUAL OPERATING COST
PER THOUSAND GALLONS TREATED
(ENERGY COST at 9¢ kw/hr)
AIR-LIFT PUMP SYSTEM
DIFFUSED AERATION SYSTEM
PACKED COLUMN
DIFFUSED AERATION
SYSTEM
INDUCED AIR PACKED COLUMN
SPRAY AERATION SYSTEM
PACKED COLUMN
AIR-STRIPPING SYSTEM
COST FEB. 1983
COST IN CENTS PER THOUSAND GALLONS TREATED
FLOW M.G.D.
0
10
20
30
40
50
1.0
2.0
3.0
4.0
5.0
6.0
7.0

FIGURE 9